

SUB-DAILY POLAR MOTION DURING EPOCH '92 WITH GPS

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ABSTRACT. Data from a worldwide Global Positioning System (GPS) tracking network spanning six days during the EPOCH '92 campaign are used to estimate variations of the Earth's pole position every 30 minutes. The resulting polar motion time series is compared with estimates derived from very long baseline interferometry (VLBI) observations. A time domain comparison of the semidiurnal and prograde diurnal bands yields better than 0.3 milliarcsecond rms differences between the series. Additional comparison with an ocean tidally-induced polar motion model suggests that most of the periodic subdaily variations in the GPS polar motion signal can be attributed to ocean tides

1. Introduction

Observations of the motion of the pole have a long history [See Lambeck, 1980; Eubanks, 1993, and references therein]. Polar motion, which is the movement of the Earth's rotation axis with respect to its crust, is a dynamic response of the Earth forced by its interactions with other celestial bodies and its own internal dynamics. The location of the rotation axis is given with respect to a crust-fixed, reference point (e.g., the International Earth Rotation Service (IERS) reference pole [McCarthy, 1992]) by using two coordinates, polar motion x (PMX) and polar motion y (PMY), where the x -axis lies along the Greenwich meridian, orthogonal to the reference pole z -axis, and the y -axis lies 90 degrees to the west.

Angular momentum changes in the oceans at daily and sub-daily periods of tidal origin, a product of the response of the world's oceans to the tidal potential at high frequencies, lead to associated diurnal and semidiurnal changes in polar motion [Seiler, 1991; Gross, 1993; Wunsch and Seiler, 1992]. Since the tendency in the polar motion is towards decreasing amplitudes at shorter periods, increasing sensitivity has been necessary to detect these high-frequency pole position changes. Herring et al. [1991] and Lindqwister et al. [1992] obtained GPS daily polar motion estimates in agreement with VLBI at the 0.5 mas (1.5 cm) level or better, and subsequently several GPS processing centers have been routinely reporting daily estimates of pole position as part of the International GPS and Geodynamics Service (IGS). We report here on sub-daily time-domain GPS-based polar motion measurements and their comparison with VLBI. The

data were collected during the intensive observing period known as IPOCH '92 (part of the SHARON '92 Campaign organized by the IERS), during which time continuous and high time resolution data were obtained by both VLBI and GPS.

2. Data Sets and Estimation Strategies

Data from 25 globally distributed GPS Rogue receivers tracking 17 GPS satellites from July 26 through July 31, 1992 were processed with the Jet Propulsion Laboratory's (JPL) GIPSY-OASIS II software. The data arc could not span more contiguous days due to anti-spoofing (AS) signal encryption on August 1-2. The JPL software and standard JPL GPS estimation strategies, incorporating Kalman filtering, are described in detail by Lichten [1990a, 1990b] and Blewitt [1993]. The estimation strategy for this study is described by Zumberge et al. [this volume]. GPS orbit states and three solar radiation parameters corresponding to three orthogonal flux components were estimated for each satellite. Earth orientation parameters were estimated by using the IERS Bulletin B time series as the source for nominal values. Earth rotation (UT1 - UTC) variations were estimated every 30 minutes starting from an initial fixed value by using first-order Markov process updates with a correlation time of 6 hours and a steady-state process noise 1-sigma constraint of 0.06 ms [Freedman et al., 1993, and this volume]. Station geocentric coordinates, except those for up to 8 fiducial (fixed) sites, were estimated as constants over the entire six day period, with ITRF 1991 coordinates [Boucher et al., 1992] used as a priori station locations. As observed by Lindqwister et al. [1992], changing fiducial sites in our estimation strategies induced only bias changes in our polar motion series, consistent with small rigid-body rotations of the reference frame. The pole position variability remained nearly invariant even in the absence of fiducial sites.

Two different estimation strategies for the satellite orbits were employed [see Zumberge et al., this volume]. The strategy which proved superior for polar motion estimation consisted of re-estimating each satellite state (position, velocity and solar radiation pressure coefficients) every 24 hours. The white noise restarts for each GPS satellite were staggered over a 5 hour interval around noon to maintain continuity in the UT1 series. We then tried a variety of estimation strategies for polar motion and found that unconstrained white noise estimates, every 30 minutes or less, gave consistent results in the prograde diurnal and semidiurnal bands discussed below. Typical postfit rms residuals were close to 6 mm for carrier phase and 35 cm for pseudo-range data.

The VLBI series used for comparison in this study was generated from data acquired by three different VLBI networks: "NASA R&D", "IRIS" and "NAVNET" (see Freedman et al. [1993], and Herring [this volume] for more details). UT1, polar motion, nutation corrections, and station troposphere parameters were estimated over 24 hour time spans, with UT1, polar motion and troposphere parameters modeled as random walks. Polar motion was estimated every 2 hours with 1.2 mas 1-sigma resets.

We have also compared our series to a model of tidally-induced polar motion variations. This model, referred to as the Herring tide model [Herring and Dong, 1993], is an empirically determined model based on eight years of VLBI observations. Because it is empirical rather than theoretical, this model may contain contributions from sources other than ocean tides, such as the atmosphere.

3. Results and Discussion

As is well known, the retrograde diurnal motion of the pole is degenerate with long period nutation, and estimates of sub-daily polar motion can be contaminated by nutation model errors (see Hubbard [1993] for a lucid discussion). This is a result of retrograde diurnal polar motion being nearly fixed in Earth-centered inertial coordinates. Similarly, in our estimation strategies, mismodeled orbital variations in the GPS constellation that appear slow in an inertial frame can be readily absorbed by the retrograde diurnal component of polar motion. To avoid ambiguities from these error sources, we removed the retrograde diurnal band in our comparisons with VLBI data sets. (The VLBI polar motion data already have very little power at retrograde diurnal periods, owing to the explicit estimation of nutation corrections in the VLBI estimation strategy.) Furthermore, since we found that non-periodic signatures in our GPS polar motion series varied significantly with estimation strategy (and observed similar behavior among preliminary VLBI solutions), we restricted comparisons in this study to the, semidiurnal (both prograde and retrograde) and diurnal prograde bands

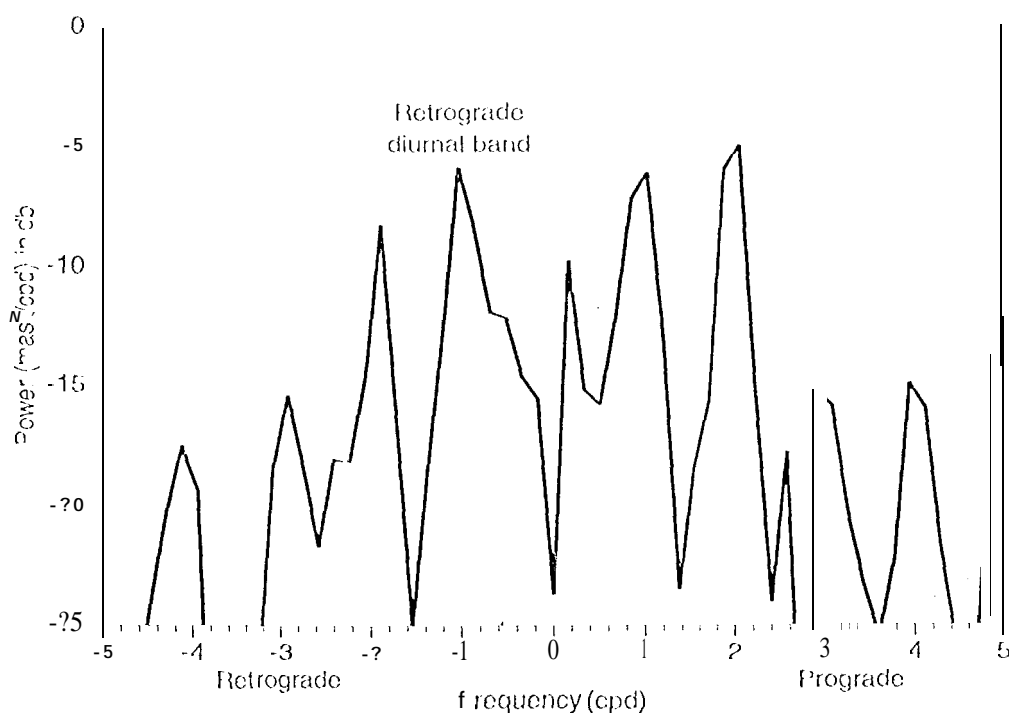


Fig. 1. GPS polar motion power spectral density.

In Figure 1, we show the power spectrum of the GPS polar motion series estimated every 30 minutes with loose (± 20 mas) constraints. As already mentioned, the GPS retrograde diurnal peak at 1 cycle/day (cpd) is contaminated by nutation and orbit mismodeling. The spectrum clearly shows *peaks* in the semidiurnal (± 2 cpd) and prograde diurnal (± 1 cpd) bands, with relatively little power elsewhere. The estimates are passed through a band reject filter so that only the ± 1 cpd and ± 2 cpd bands, with bandwidths of 0.4 cpd, are retained. Identical filtering is applied to the VLBI series prior to comparison with the GPS data.

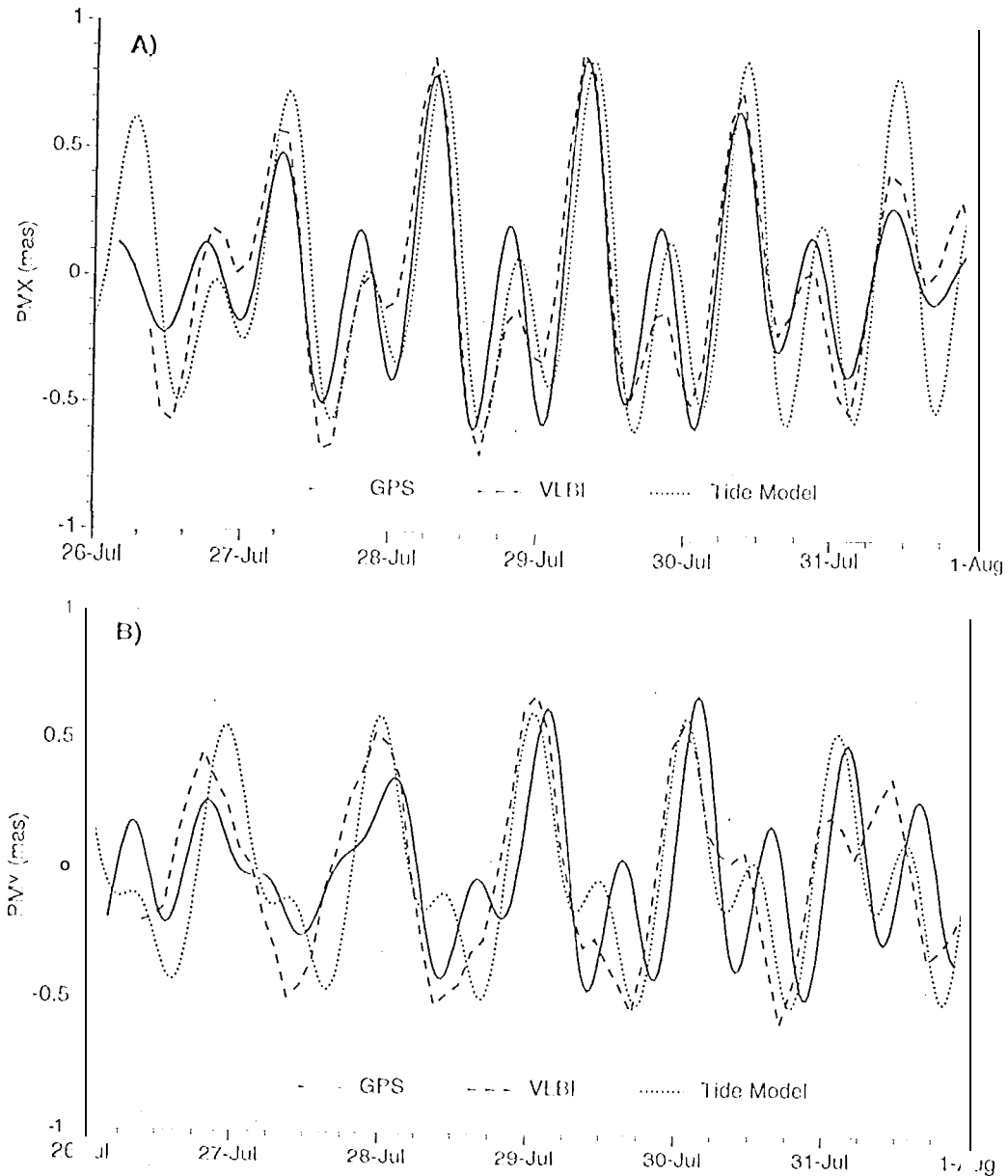


Fig. 2. (a) PMX semidiurnal and prograde diurnal bands for the GPS, VLBI, and Herring tide model time series. (b) Same as (a), but for PMY.

Figure 2 shows time-domain PMX and PMY plots of the diurnal (prograde) and semidiurnal (prograde and retrograde) bands of both the GPS and VLBI series, together with the Herring tide model. The rms difference between the VLBI and GPS series is 0.17 and 0.29 mas in PMX and PMY respectively. The overall level of agreement in both amplitude and phase is noteworthy, particularly in the x -component, and especially in light of the fact (that the approximately 12-hour orbits of the GPS satellites might lead one to expect poor results at semidiurnal frequencies. Comparison statistics on rms differences and series cross-correlations are given in Table 1. The results in the table suggest that most of the GPS signal in Figure 2 can be attributed to ocean tides. The polar motion results presented here are very encouraging, and are consistent with simi-

lar good agreement between GPS and VLBI estimates of sub-daily UT1 variability [Freedman et al., 1993, and this volume]. We hope that this study will help in part to motivate future intensive VLBI campaigns to provide high-quality data for intercomparison with GPS.

Table J. RMS Differences and Correlations

	x rms (mas)	y rms (mas)	x corr.	y Corr.
VLBI - GPS	0.17	0.29	0.90	0.55
Tide Model - GPS	0.26	0.26	0.78	0.60
Tide Model - VLBI	0.25	0.26	0.80	0.77

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4. References

- Boucher, C., Z. Altamimi, and L. Duham, ITRF 91 and Its Associated Velocity Field, *IERS Technical Note* 12, Central Bureau of IERS, Observatoire de Paris, October 1992.
- Blewitt, G., Advances in Global Positioning System Technology for Geodynamics Investigations: 1978-1992, in *Contributions of Space Geodesy to Geodynamics: Technology*, edited by D. E. Smith and D. L. Turcotte, pp. 195-213, Am. Geophys. Un., Washington, D.C., 1993.
- Bubanks, T. M., Variations in the Orientation of the Earth, in *Contributions of Space Geodesy to Geodynamics: Earth Dynamics*, edited by D. E. Smith and D. L. Turcotte, pp. 1-54, Am. Geophys. Un., Washington, D.C., 1993.
- Freedman, A. P., R. Ibáñez-Meier, S. M. Lichten, J. O. Dickey, and T. A. Herring, Sub-Daily Earth Rotation During the IPOCH'92 Campaign, *Geophys. Res. Lett.*, submitted, 1993.
- Gross, R. S., The Effect of Ocean Tides on the Earth's Rotation as Predicted by the Results of an Ocean Tide Model, *Geophys. Res. Lett.*, 20, 293-296, 1993.
- Herring, T. A., D. Dong, and R. W. King, Submilliarcsecond Determination of Pole Position using Global Positioning System 1 Data, *Geophys. Res. Lett.*, 18, 1893-1897, 1991.
- Herring, T. A., and D. Dong, Measurement of Diurnal and Semidiurnal Rotation Variations and Tidal Parameters of the Earth, *J. Geophys. Res.*, submitted, 1993.
- Lambeck, K., *The Earth's Variable Rotation: Geophysical Causes and Consequences*, 449 pp., Cambridge University Press, New York, 1980.
- Lichten, S. M., Toward GPS Orbit Accuracy of Tens of Centimeters, *Geophys. Res. Lett.*, 17, 15-18, 1990a.
- Lichten, S. M., Estimation and Filtering for High Precision GPS Positioning Applications, *Man. Geod.*, 15, 159-176, 1990b.
- Lindqwister, U. J., A. P. Freedman, and G. Blewitt, Daily Estimates of the Pole Position With the Global Positioning System, *Geophys. Res. Lett.*, 19, 845-848, 1992.
- McCarthy, D. D. (ed.), *IERS Standards*, *IERS Technical Note* 3, Central Bureau of IERS, Observatoire de Paris, 1992.
- Seiler, U., Periodic Changes of the Angular Momentum Budget Due to the Tides of the World Ocean, *J. Geophys. Res.*, 96, 10287-10300, 1991.
- Wunsch, J., and U. Seiler, Theoretical Amplitudes and Phases of the Periodic Polar Motion Terms Caused by Ocean Tides, *Astron. Astrophys.*, 266, 581-587, 1992.